A Novel Reactor Neutrino Experiment for Measuring the Mixing Angle θ_{13}

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Recent experimental results indicate that neutrinos have a small but finite mass and mix from one type to another. The phenomenon of neutrino mixing is characterized by the coupling between the neutrino flavor ($\nu_{e,\mu,\tau}$) and mass eigenstates ($\nu_{1,2,3}$) and the associated mixing angles. Previous neutrino oscillation experiments, including SNO and KamLAND, have determined two of the three mixing angles in the neutrino mixing matrix, U_{MNSP}. Using two or multiple neutrino detectors placed at different distances from a nuclear power plant, the goal of the proposed new reactor neutrino experiment is to discover and measure the coupling of the electron neutrino flavor to the third mass eigenstate, U_{e3}, the last undetermined element of the neutrino mixing matrix.

$$U_{MNSP} = \begin{pmatrix} U_{e1} & U_{e2} & U_{e3} \\ U_{\mu 1} & U_{\mu 2} & U_{\mu 3} \\ U_{\tau 1} & U_{\tau 2} & U_{\tau 3} \end{pmatrix}$$

$$= \underbrace{\begin{pmatrix} 1 & 0 & 0 \\ 0 & c_{23} & s_{23} \\ 0 & -s_{23} & c_{23} \end{pmatrix}}_{\text{atmospheric } \nu} \underbrace{\begin{pmatrix} c_{13} & 0 & s_{13}e^{-i\delta_D} \\ 0 & 1 & 0 \\ -s_{13}e^{i\delta_D} & 0 & c_{13} \end{pmatrix}}_{\text{reactor/accelerator } \nu} \underbrace{\begin{pmatrix} c_{12} & s_{12} & 0 \\ -s_{12} & c_{12} & 0 \\ 0 & 0 & 1 \end{pmatrix}}_{\text{solar } \nu}$$

The current best upper limit on U_{e3} comes from the CHOOZ reactor neutrino disappearance experiment [1]. In contrast to the surprisingly large mixing of the other neutrino states, the U_{e3} coupling was found to be small. However, the size of U_{e3} and its oscillation effects have not yet been measured.

Neutrino oscillation experiments play an important role in understanding the physics of massive neutrinos. They determine the fundamental neutrino mixing parameters and help us answer fundamental questions related to the physics at high mass scales, the physics of flavor, and unification. A measurement of θ_{13} may help us answer some of the central questions in neutrino physics:

• *Why are the neutrino mixing angles large, maximal, and small?* • *Is there CP, T, or CPT violation in the lepton sector?* • *Is there a connection between the lepton and the baryon sector?*

The discovery of subdominant effects in $\overline{\nu}_e \rightarrow \overline{\nu}_{\mu,\tau}$ oscillations and a non-zero U_{e3} coupling would have a profound impact on neutrino physics. It determines whether CP violation can play a significant role in lepton mixing. CP violation is a well-established phenomenon in the quark sector but leptonic CP violation is as yet unknown. CP violation in the lepton sector could have cosmological implications far beyond the phenomenon on neutrino oscillations. It may be the only way to explain the observed matter-antimatter asymmetry in the Universe. In this context a successful θ_{13} experiment has the potential to define the direction of neutrino research and the neutrino program at accelerators for the next decade and beyond. The small size of θ_{13} compared to the other neutrino mixing angles may also point us to an underlying symmetry in theoretical neutrino mass models.

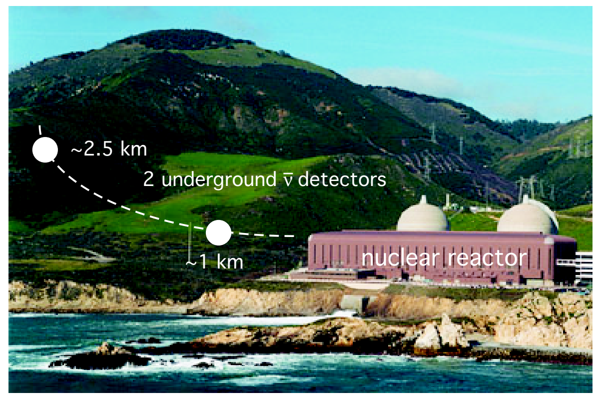

FIG. 1: Concept of a 2-detector neutrino oscillation experiment at the Diablo Canyon nuclear power plant in California.

We have studied the concept of a novel reactor neutrino oscillation experiment that improves our knowledge of θ_{13} by an order of magnitude. The proposed experiment includes two or perhaps multiple liquid scintillator detectors placed at distances up to 3 km from the reactor. The relative comparison of the observed $\overline{\nu}_e$ rates and spectra allows one to detect subdominant oscillations due to U_{e3}. Critical for the design of this experiment is an underground location near a powerful nuclear power plant. A horizontal tunnel with $\geq$ 300 mwe overburden for shielding of cosmic rays would provide a variable baseline and help control systematic effects. Several suitable reactor sites in the US have been identified and negotiations with power plants are underway.

[1] M. Apollonio et al., Eur.Phys.J.C27:331-374 (2003)
[2] For further information see: http://theta13.lbl.gov/